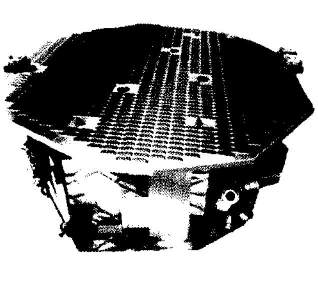
esa *LISA PATHFINDER*

Robin Stebbins on behalf of the LISA Pathfinder Science Working Team



The LISA Pathfinder spacecraft

LISA Pathfinder is a space mission dedicated to demonstrating technology for the Laser Interferometer Space Antenna (LISA). LISA is a joint ESA/NASA mission to detect low-frequency gravitational waves in the 0.0001 to 0.1 Hz frequency band. LISA is expected to observe 100's of merging massive black hole binaries out z~15, tens of thousands of close compact binary systems in the Milky Way, merging intermediate-mass black hole binaries, tens of stellar-mass black holes falling into supermassive black holes in galactic centers, and possibly other exotic sources.

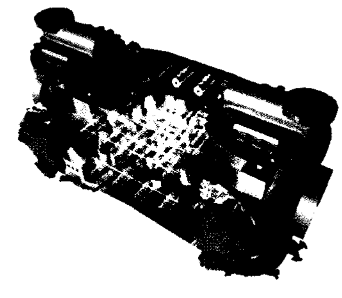
Several critical LISA technologies have not been demonstrated at the requisite level of performance in spaceflight, and some flight hardware cannot be tested in a 1-g environment. Hence, the *LISA Pathfinder* mission is being implemented to demonstrate these critical LISA technologies in a relevant flight environment.

LISA Pathfinder mimics one arm of the LISA constellation by shrinking the 5-million-kilometer armlength down to a few tens of centimeters. The experimental concept is to measure the relative separation between two test masses nominally following their own geodesics, and thereby determine the relative residual acceleration between them near 1 mHz, about a decade above the lowest frequency required by LISA.

To implement such a concept, disturbances on the test masses must be kept very small by many design features, but chiefly by "drag-free" flight. A drag-free spacecraft follows a free-falling test mass which it encloses, but has no mechanical connection to. The spacecraft senses its orientation and separation with respect to the proof mass, and its propulsion system is commanded to keep the spacecraft centered about the test mass. Thus, the spacecraft shields the test mass from most external influences, and minimizes the effects of force gradients arising from the spacecraft, and acting on the test mass. *LISA Pathfinder* will compare the geodesic of one test mass against that of the other.

Only a metrology system based on interferometry can achieve the displacement sensitivity. interferometers monitor the separation of both test masses with a sensitivity comparable to that required by LISA, and using the same technologies.

LISA Pathfinder is scheduled to be launched in the first half of 2010 to a Lissajous orbit around the first Sun-Earth Lagrange point, L1. In addition to a complete European technology package (the LISA Technology Package, or LTP), *LISA Pathfinder* will also carry thrusters and software, known as ST-7, a part of NASA's New Millennium Program.



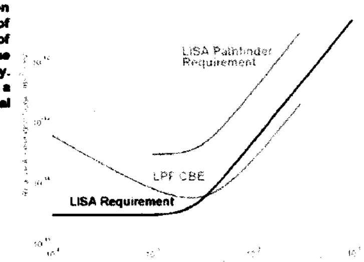
The European provided LISA Technology Package

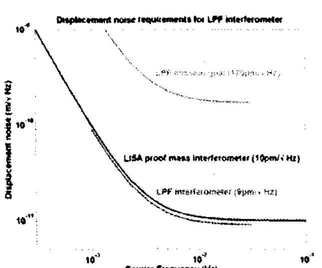
Top Level Requirements for the *LISA Pathfinder* Mission

The primary goal of LISA Pathfinder (LPF) mission is to verify that a LISA-like test mass can be free of disturbances within an order of magnitude of LISA's residual acceleration requirement. The one order of magnitude rule applies also to frequency. Thus the top level requirement on the LTP is a residual acceleration noise (i.e., amplitude spectral density) of one test mass relative to the other of

$$S_a^{1/2}(f) \le 3\times10^{-14}\left[1+\left(\frac{f}{3mHz}\right)^2\right] ms^{-2}/\sqrt{Hz}$$

Over the frequency range, *f*, of 1 to 30mHz.





A secondary goal of the mission is to demonstrate picometer interferometry to free-floating mirrors. This goal is also directly applicable to LISA: the LISA armlength is measured in a three-step process - by measuring the displacement from test mass to optical bench, from local optical bench to far optical bench, and finally far optical bench to far test mass (on the other spacecraft). In this case, the LTP requirement is similar to that of LISA, namely:

$$S_{\delta x}^{1/2} \le 9\times10^{-12}\left[1+\left(\frac{3mHz}{f}\right)^2\right] m/\sqrt{Hz}$$

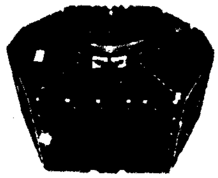
Over the frequency range, f, of 1 to 30mHz

LISA Pathfinder Status

The LISA Technology Package successfully passed the Critical Design Review in November 2007. This **review paves the way for the production and procurement of the LTP flight hardware. The Critical Design Review of the *LISA Pathfinder* system is scheduled for mid-2008. However, spacecraft flight hardware has already been delivered or is awaiting delivery to the LPF prime contractor.**

Flight **units which have been delivered include:**

Digital sun sensor flight unit



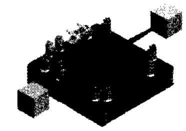
The LISA Pathfinder flight structure

Spacecraft separation system flight unit

The LTP Team photograph

Technology Demonstrated by *LISA Pathfinder*

The general philosophy of the LTP is to build to the LISA **requirements, to measure to the LISA sensitivity,** but allow the **higher acceleration noise of the L1 environment.** This produces **hardware directly transferable to LISA, and noise** assessment at **LISA levels.**



Concept drawing of the LTP

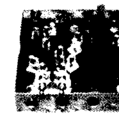
The interferometry equipment immediately applicable to LISA **includes: the laser, the optical bench and the phase** meter. The **inertial sensor equipment includes: the test mass,** the electrode **housing, the front-end electronics, the caging mechanism,** the **charge control subsystem, and the vacuum system.** Micronewton **thrusters are another essential LISA technology** to be demonstrated

Engineering model (EM) of the LTP Laser

Frequency noise of the free running laser

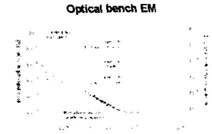
The laser source used **in the LTP is a Nd:YAG** non-planar ring oscillator **emitting ~25mW at 1064 nm.** This laser is identical **to the master oscillator** proposed for LISA. **The laser light is coupled into a** single-mode, polarisation-**maintaining optical fiber,** before being split **into two paths, each of which is** directed to an Acousto-**Optic Modulator (AOM). The** difference in the drive **frequencies of the AOMs** defines the heterodyne **signal of the interferometers.** The light is then delivered **by fiber to the optical** bench. The flight **model is scheduled for delivery in** July 2008.

The laser light is coupled onto the optics bench via quasi-monolithic fiber injectors manufactured from fused silica. The fiber injectors are bonded to the Zerodur optical bench using potassium hydroxide catalysis bonding. The mirrors, also manufactured from fused silica, are bonded to the optics bench using the same technique as the fiber injectors. The optical bench is essentially one solid piece of glass: the only movable mirrors in the interferometer are the free-falling test masses.



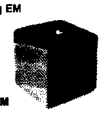
Optical bench EM

The four interferometers on the bench measure: (1) the differential motion of the test masses; (2) the displacement of one test mass with respect to the optics bench; (3) the frequency noise of the laser; and (4) a reference length. The outputs from the interferometer photodiodes are fed into a multi-channel phasemeter that tracks the phase of the heterodyne signal. The flight models of the phasemeter and optical bench are scheduled for delivery in March and August 2008, respectively.



Performance of interferometer and phasemeter (green curve)

Electrode Housing EM



Test Mass EM

The test masses in the LTP are 46 mm cubes **of a gold/platinum alloy.** Au:Pt is chosen for its high density and extremely **low magnetic susceptibility,** with the correct alloy ratio. The position of the **mass is measured using the** interferometer in the sensitive x-axis, and by **capacitive sensing in all six** degrees of freedom. The capacitor consists of the **gold coated sides of the** test mass and gold coated, sapphire electrodes **in the electrode housing.** To minimise the effects, for example of residual **gas damping, the electrode** housing is mounted inside a vacuum system. **Also within the vacuum tank** is a caging mechanism to hold the test mass **during launch and position it** (with zero momentum) once on-orbit. The **charge on the proof mass is** sensed electrostatically and controlled with **UV light, fiber-fed from mercury** lamps. Together, these subsystems **comprise the Inertial Sensor** Subsystem, the core of the *LISA Pathfinder* **mission. The flight models of** the inertial sensor system and its front end **electronics will be delivered in** the first quarter 2009.

The output of the interferometer forms the primary input to the Drag-Free and Attitude Control System (DFACS) – the set of control algorithms which keeps the spacecraft centered on the test-masses by actuating micro-Newton thrusters. LPF will carry two sets of control laws and two sets of thrusters; one set each from ESA and NASA. The European thrusters are based on Field Emission Electric Propulsion (FEEP). Currently two different architectures of FEEP thrusters are being developed; one based on a slit emitter with a cesium propellant, and the other on needle emitters with Indium propellant. Flight models are scheduled for delivery no later than March 2009.

Colloidal Thruster cluster.

In the US, a third type of micro-Newton thruster is being developed. This thruster is also based on ion emission with a colloidal solution as propellant. US flight hardware is scheduled for delivery to ESA in April 2008.

Cs FEEP

More information on *LISA Pathfinder* can be found at http://sci.esa.int/lisapf
or http://www.rssd.esa.int/index.php?project=LISAPATHFINDER&page=index